# ANSWERS TO PROBLEMS

IN THE

# INTRODUCTION

TO

# CHEMICAL PHILOSOPHY

BY

WILLIAM A. TILDEN, D.Sc. LOND., F.R.S.

PROFESSOR OF CHEMISTRY IN THE MASON COLLEGE
BIRMINGHAM

LONDON
LONGMANS, GREEN, AND CO.
1884

Price One Shilling

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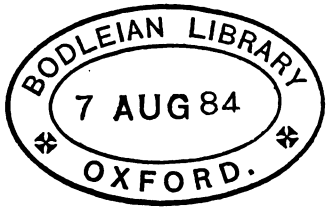


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## ANSWERS TO PROBLEMS.

SOLUTIONS are not supplied in those cases in which the answer is to be found plainly stated in the text, nor to those few questions which require for a satisfactory answer a lengthy discussion.

# ANSWERS TO PROBLEMS

IN

# TILDEN'S

# CHEMICAL PHILOSOPHY.

## SECTION I.

1 ·4141 c.c.

2. (*a*) 1·2705 c.c.

(*b*) Nitrogen 65·28, oxygen 34·72 per cent.

3. 1239·861 c.c.

4. 39107·1 c.c., or 39·1071 litres.

5. Neglecting the change in the relative pressures of the two gases consequent upon their unequal solubility. Oxygen 24·61, nitrogen 75·39 per cent.

Or, correctly as follows—

There are 4 volumes of water, 1 volume of oxygen, and 3 volumes nitrogen.

Let the residual oxygen after absorption be $1-x$.

Residual nitrogen $3-y$.

The oxygen forms $\frac{1-x}{4-x-y}$ of the whole, and is therefore at that pressure.

The oxygen dissolved is therefore

$$4\times\cdot04114\times\frac{1-x}{4-x-y}=x \quad . \quad . \qquad \text{I.}$$

Similarly the nitrogen dissolved is

$$4 \times \cdot 02035 \times \frac{3-y}{4-x-y} = y \quad . \quad . \quad . \quad \text{II.}$$

Let $4 \times \cdot 04114 = a$ ; $4 \times \cdot 02035 = b$.

Then multiply I. by $b$ and II. by $a$, and add together,

$$\text{whence } x = \frac{a}{b}(b-y).$$

Substitute this in Equation II.

$$\frac{(3-y)b}{4-y-\frac{a}{b}(b-y)} = y$$

$$(b-a)y^2 - (b^2+4b-ab)y = -3b^2$$

$$-\cdot 07236\, y^2 - (\cdot 0085 + \cdot 3688 - \cdot 01517)y = -\cdot 0255$$

$$\cdot 07236\, y^2 + \cdot 36213\, y = \cdot 0255.$$

Divide by $\cdot 07236$.

$$y^2 + 5\cdot 00456\, y = \cdot 3524$$

$$y^2 + 5\cdot 00456\, y + 2\cdot 5023^2 = \cdot 3524 + 2\cdot 5023^2$$

$$y = \cdot 0694.$$

Substitute this value of $y$ in Equation II.

and $$x = \cdot 03717.$$

Whence the residual oxygen is $1 - \cdot 03717$.

„ „ nitrogen is $3 - \cdot 0694$.

Oxygen = ·96283, or 24·73 per cent.

Nitrogen = 2·9306, or 75·27 „

This is the composition of the residual air.

6. Chlorine to hydrogen ·1678 to 1, or nearly 1 to 6.

7. Hydrogen, 1 : carb. anhyd., ·2132 : ozone, ·2041.

8. 1·52 (air = 1), or 21·9 (hydn. = 1).

9. ·9575.

10. An approximate solution is obtained as follows :—

At the end of the 1st second the hydrogen which has entered is 3·83, whilst the oxygen which has escaped is

$\frac{1}{4}$ of 3·83, or ·96. The composition of the mixture is therefore

$$19{\cdot}04\ \mathrm{O} + 3{\cdot}83\ \mathrm{H}.$$

Assuming that the supply of hydrogen outside is indefinitely large, inter-diffusion will then occur between hydrogen and a mixture consisting of

$$\frac{3{\cdot}83}{22{\cdot}87}\ \mathrm{H} \text{ and } \frac{19{\cdot}04}{22{\cdot}87}\ \mathrm{O}.$$

The hydrogen which returns outwards from this mixture in the next second is

$$\frac{3{\cdot}83}{22{\cdot}87} \text{ of } 3{\cdot}83, \text{ or } {\cdot}64 \text{ c.c.},$$

and the oxygen escaping is

$$\frac{10{\cdot}04}{22{\cdot}87} \text{ of } {\cdot}96, \text{ or } {\cdot}8 \text{ c.c.}$$

At the end of the 2nd second, therefore, the mixture will consist of—

| | Oxygen | | Hydrogen |
|---|---|---|---|
| | (19·04 − ·8) | + | (3·83 − ·64 + 3·83) |
| or | 18·24 | + | 7·02. |

Proceeding in the same manner, the hydrogen entering in the 3rd second is 3·83.

The hydrogen escaping is

$$\frac{7{\cdot}02}{25{\cdot}26} \text{ of } 3{\cdot}83 = 1{\cdot}06.$$

The oxygen escaping is

$$\frac{18{\cdot}24}{25{\cdot}26} \text{ of } {\cdot}96 = {\cdot}69.$$

Whence at the end of the 3rd second the mixture is

| | Oxygen | | Hydrogen |
|---|---|---|---|
| | (18·24 − ·69) | + | (7·02 − 1·06 + 3·83) |
| or | 17·55 | + | 9·79. |

11. 94·93 c.c.

12. 256·71 c.c.
13. 14·42 atmospheres.
14. 1033·296 grams, or 1 kilo. and 33·296 grams.
15. 101970 grams, or 101 kilos. and 970 grams.
16. 16·3152 grams per sq. centimetre.
17. ·1650 gram.
18. 1·2544 gram ; 19·712 grams ; ·3584 gram.
19. 107·3 c.c. ; 105·6 c.c. ; 136·6 c.c.
20. If V be the volume at 75°, it will be ·7844 V at 0°.
21. 1218·9 c.c.
22. 553 c.c.
23. 264·7 c.c.
24. 55·26 c.c.
25. −77°·6.
26. $\frac{5}{2457}$, or ·002036.
27. 142·03 c.c.
28. 58·38 c.c.
29. 590·9 mm.
30. 130·49 litres.

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## SECTION II.

3. O represents one atom of oxygen.

$O_2$ represents one molecule of oxygen, consisting of two atoms.

| | Molecules | | | Each consisting of |
|---|---|---|---|---|
| $OH_2$ | represents | 1 | of water . . . | 1 atom of oxygen.<br>2 atoms of hydrogen |
| $2OH_2$ | ,, | 2 | ,, water . . . | ditto ditto |
| HCl | ,, | 1 | ,, hydrogen chloride or hydrochloric acid | 1 atom of hydrogen<br>1 atom of chlorine |
| $H_2$ | ,, | 1 | ,, hydrogen . . | 2 atoms of hydrogen |
| $Cl_2$ | ,, | 1 | ,, chlorine . . | 2 atoms of chlorine |
| $NH_3$ | ,, | 1 | ,, ammonia . . | 1 atom of nitrogen<br>3 atoms of hydrogen |
| $H_3PO_4$ | ,, | 1 | ,, hydrogen phosphate or phosphoric acid . | 3 atoms of hydrogen<br>1 atom of phosphorus<br>4 atoms of oxygen |

| | Molecules | | | Each consisting of |
|---|---|---|---|---|
| $H_2SO_4$ | represents | 1 | of hydrogen sulphate or sulphuric acid | 2 atoms of hydrogen<br>1 atom of sulphur<br>4 atoms of oxygen |
| $FeSO_4$ | ,, | 1 | ,, ferrous sulphate . | 1 atom of iron<br>1 atom of sulphur<br>4 atoms of oxygen |
| $2FeSO_4$ | ,, | 2 | ,, ferrous sulphate . | ditto ditto |
| $Al_2(SO_4)_3$ | ,, | 1 | ,, aluminic sulphate . | 2 atoms of aluminium<br>3 atoms of sulphur<br>12 atoms of oxygen |
| $12OH_2$ | ,, | 12 | ,, water . . . | 1 atom of oxygen<br>2 atoms of hydrogen |
| $12Al_2(SO_4)_3$ | ,, | 12 | ,, aluminic sulphate . | as above |
| $CO_2$ | ,, | 1 | ,, carbon dioxide or carbonic anhydride | 1 atom of carbon<br>2 atoms of oxygen |
| $3CO_2$ | ,, | 3 | ,, ditto ditto . | ditto ditto |

4.

| | Formula | Molecular Weight |
|---|---|---|
| Water . . . | $OH_2$ or $H_2O$ | 18 |
| Ammonia . . | $NH_3$ | 17 |
| Hydrochloric acid . | $HCl$ | 36·5 |
| Carbonic anhydride . | $CO_2$ | 44 |
| Sulphuric acid . | $H_2SO_4$ | 98 |
| Ferrous sulphate . | $FeSO_4$ | 152 |
| Aluminic sulphate . | $Al_2(SO_4)_3$ | 342·6 |
| Phosphoric acid . | $H_3PO_4$ | 98 |

5.

| | |
|---|---|
| $2HgO$ | = 432 |
| $10OH_2$ | = 180 |
| $3FeS$ | = 264 |
| $3FeS_2$ | = 360 |
| $2CS_2$ | = 152 |
| $KC_4H_5O_6$ | = 188·1 |
| $K_2C_4H_4O_6$ | = 226·2 |
| $5C_7H_9N$ | = 535 |
| $12CH_4$ | = 192 |
| $KAl(SO_4)_2 + 12OH_2$ | = 474·4 |
| $3[NH_4Cr(SO_4)_2 + 12OH_2]$ | = 1434 |

6. BaO — Barium monoxide (baryta).
CaO — Calcium monoxide (lime).
MgO — Magnesium monoxide (magnesia).
ZnS — Zinc sulphide.
KCl — Potassium chloride.
NaBr — Sodium bromide.
AgF — Silver fluoride.
$H_2S$ — Hydrogen sulphide (sulphuretted hydrogen).
HI — Hydrogen iodide (hydriodic acid).
KCN or KCy — Potassium cyanide.
SSe — Sulphur selenide.
BN — Boron nitride.
$H_3P$ — Hydrogen phosphide (phosphine).

7. BaO — Barium monoxide.
$BaO_2$ — Barium dioxide.
$Hg_2O$ — Mercurous oxide.
HgO — Mercuric oxide.
FeS — Iron monosulphide or ferrous sulphide.
$FeS_2$ — Iron disulphide (iron pyrites).
MnO — Manganese monoxide, or manganous oxide.
$Mn_2O_3$ — Manganese sesquioxide, or manganic oxide.
$MnO_2$ — Manganese dioxide, or manganic peroxide.
FeO — Iron monoxide, or iron protoxide, or ferrous oxide.
$Fe_2O_3$ — Iron sesquioxide, or iron peroxide, or ferric oxide.
$Fe_3O_4 = FeO + Fe_2O_3$ — Ferroso-ferric oxide (magnetic oxide of iron).
$N_2O$ — Nitrogen monoxide, or nitrous oxide.
$N_2O_2$ — Nitrogen dioxide, or nitric oxide. (For the formula of nitric oxide, see p. 153.)
$N_2O_3$ — Nitrogen trioxide, or nitrous anhydride.
$N_2O_4$ — Nitrogen tetroxide, or nitric peroxide.
$N_2O_5$ — Nitrogen pentoxide, or nitric anhydride.

| | | |
|---|---|---|
| | $P_2S_3$ | Phosphorus trisulphide, or phosphorous sulphide. |
| | $P_2S_5$ | Phosphorus pentasulphide, or phosphoric sulphide. |
| | $SnCl_2$ | Tin dichloride, or stannous chloride. |
| | $SnCl_4$ | Tin tetrachloride, or stannic chloride. |
| | $FeBr_2$ | Ferrous bromide. |
| | $Fe_2Br_6$ | Ferric bromide. |
| | $Cu_2Cl_2$ | Cuprous chloride. |
| | $CuCl_2$ | Cupric chloride. |
| | $CrCl_2$ | Chromous chloride. |
| | $Cr_2Cl_6$ | Chromic chloride. |
| | $CrF_6$ | Chromium or chromic hexfluoride. |
| | $SbBr_3$ | Antimony tribromide or antimonious bromide. |
| | $SbBr_5$ | Antimony pentabromide or antimonic bromide. |
| 8. | $KNO_2$ | Potassium nitrite. |
| | $KNO_3$ | Potassium nitrate. |
| | $K_2SO_3$ | Potassium sulphite. |
| | $K_2SO_4$ | Potassium sulphate. |
| | $KCl$ | Potassium chloride. |
| | $KClO$ | Potassium hypochlorite. |
| | $KClO_2$ | Potassium chlorite. |
| | $KClO_3$ | Potassium chlorate. |
| | $KClO_4$ | Potassium perchlorate. |
| | $KI$ | Potassium iodide. |
| | $KIO_3$ | Potassium iodate |
| | $KIO_4$ | Potassium periodate. |
| | $NaHSO_3$ | Sodium hydrogen sulphite. |
| | $Na_2SO_3$ | Sodium sulphite. |
| | $Na_2HPO_4$ | Disodium hydrogen phosphate. |
| | $Na_3PO_4$ | Trisodium phosphate. |
| | $NaH_2PO_4$ | Sodium dihydrogen phosphate. |
| | $H_3PO_2$ | Hypophosphorous acid, or hydrogen hypophosphite. |
| | $H_3PO_3$ | Phosphorous acid or hydrogen phosphite. |

$H_3PO_4$ Phosphoric acid or hydrogen phosphate.
$HCl$ Hydrochloric acid or hydrogen chloride.
$HClO$ Hypochlorous acid or hydrogen hypochlorite.
$HBrO$ Hypobromous acid or hydrogen hypobromite.
$HClO_2$ Chlorous acid or hydrogen chlorite.
$HClO_3$ Chloric acid or hydrogen chlorate.
$HIO_3$ Iodic acid or hydrogen iodate.
$HClO_4$ Perchloric acid or hydrogen perchlorate.
$HBrO_4$ Perbromic acid or hydrogen perbromate.

9.

| | No. of mols. | Name | Weight of 1 mol. | Whole weight used | Whole weight obtained |
|---|---|---|---|---|---|
| *a.* $MnO_2$ | 1 | Manganese dioxide | 87 | 87 } = 233 | |
| $4HCl$ | 4 | Hydrochloric acid | 36·5 | 146 } | |
| $MnCl_2$ | 1 | Manganese chloride | 126 | | 126 } |
| $Cl_2$ | 1 | Chlorine | 71 | | 71 } = 233 |
| $2H_2O$ | 2 | Water | 18 | | 36 } |
| *b.* $2KI$ | 2 | Potassium iodide | 166·1 | 332·2 } = 403·2 | |
| $Cl_2$ | 1 | Chlorine | 71 | 71 } | |
| $2KCl$ | 2 | Potassium chloride | 74·6 | | 149·2 } = 403·2 |
| $I_2$ | 1 | Iodine | 254 | | 254 } |
| *c.* $SO_2$ | 1 | Sulphur dioxide | 64 | 64 } | |
| $2OH_2$ | 2 | Water | 18 | 36 } = 171 | |
| $Cl_2$ | 1 | Chlorine | 71 | 71 } | |
| $H_2SO_4$ | 1 | Sulphuric acid | 98 | | 98 } |
| $2HCl$ | 2 | Hydrochloric acid | 36·5 | | 73 } = 171 |
| *d.* $NaNO_3$ | 1 | Sodium nitrate | 85 | 85 } = 183 | |
| $H_2SO_4$ | 1 | Hydrogen sulphate | 98 | 98 } | |
| $NaHSO_4$ | 1 | Sodium hydrogen sulphate | 120 | | 120 } |
| $HNO_3$ | 1 | Hydrogen nitrate | 63 | | 63 } = 183 |
| *e.* $2MnO_2$ | 2 | Manganese dioxide | 87 | 174 } = 370 | |
| $2H_2SO_4$ | 2 | Hydrogen sulphate | 98 | 196 } | |
| $2MnSO_4$ | 2 | Manganese sulphate | 151 | | 302 } |
| $2H_2O$ | 2 | Water | 18 | | 36 } = 370 |
| $O_2$ | 1 | Oxygen | 32 | | 32 } |
| *f.* $2K_2Cr_2O_7$ | 2 | Potassium dichromate | 294·2 | 588·4 } = 1372·4 | |
| $8H_2SO_4$ | 8 | Hydrogen sulphate | 98 | 784 } | |
| $2K_2SO_4$ | 2 | Potassium ,, | 174·2 | | 348·4 } |
| $2Cr_2(SO_4)_3$ | 2 | Chromium ,, | 392 | | 784 } = 1372·4 |
| $8H_2O$ | 8 | *Water* | 18 | | 144 } |
| $3O_2$ | 3 | *Oxygen* | 32 | | 96 } |

10.

| | No. of molecules | Name | Weight of 1 mol. | Whole weight | Whole volume |
|---|---|---|---|---|---|
| *a.* $2OH_2$ | 2 | Water gas (steam) | 18 | 36 used | 4 used |
| $2Cl_2$ | 2 | Chlorine | 71 | 142 ,, | 4 ,, |
| $4HCl$ | 4 | Hydrochloric acid | 36·5 | 146 obtd. | 8 obtd. |
| $O_2$ | 1 | Oxygen | 32 | 32 ,, | 2 ,, |
| *b.* $CO_2$ | 1 | Carbon dioxide | 44 | 44 used | 2 used |
| C | 1 *atom* | Carbon | 12 (*atomic* weight) | 12 ,, | solid volume relation |
| | Molecular weight unknown | | | | unknown |
| $2CO$ | 2 | Carbon monoxide | 28 | 56 obtd. | 4 |
| *c.* $2CO$ | 2 | Carbon monoxide | 28 | 56 used | 4 used |
| $O_2$ | 1 | Oxygen | 32 | 32 ,, | 2 ,, |
| $2CO_2$ | 2 | Carbon dioxide | 44 | 88 obtd. | 4 obtd. |
| *d.* $2NH_3$ | 2 | Ammonia | 17 | 34 used | 4 used |
| $N_2$ | 1 | Nitrogen | 28 | 28 obtd. | 2 obtd. |
| $3H_2$ | 3 | Hydrogen | 2 | 6 ,, | 6 ,, |
| *e.* $2NH_3$ | 2 | Ammonia | 17 | 34 used | 4 used |
| $3Cl_2$ | 3 | Chlorine | 71 | 213 ,, | 6 ,, |
| $N_2$ | 1 | Nitrogen | 28 | 28 obtd. | 2 obtd. |
| $6HCl$ | 6 | Hydrochloric acid | 36·5 | 219 ,, | 12 ,, |
| *f.* $NH_4NO_3$ | 1 | Ammonium nitrate | 80 | 80 used | solid |
| $N_2O$ | 1 | Nitrous oxide | 44 | 44 obtd. | 2 obtd. |
| $2H_2O$ | 2 | Water | 18 | 36 ,, | 4 ,, |

11. (*a*) $2NH_4Cl + Ca(HO)_2 = 2NH_3 + CaCl_2 + 2H_2O$.
(*b*) $NH_4NO_2 = N_2 + 2H_2O$.
(*c*) $NaCl + H_2SO_4 = NaHSO_4 + HCl$.
(*d*) $3Cu + 8HNO_3 = 3Cu(NO_3)_2 + 2NO + 4H_2O$.
(*e*) $Hg + 2H_2SO_4 = HgSO_4 + SO_2 + 2H_2O$.
(*f*) $Sb_2S_3 + 6HCl = 2SbCl_3 + 3H_2S$.

12. 64 grams and 32 grams.
13. 141·3 pounds.
14. 32·65 kilograms.
15. 137·2 pounds.
16. 265·7 pounds.
17. 28·672 grams ; 159·04 grams ; 190·4 grams.

18. (α) To form carbon monoxide, 1 litre; or carbon dioxide, 2 litres.

(β) To form sulphur dioxide, 1·395 litre; or sulphur trioxide, 2·0925 litres.

(γ) 9·3 or 18·6 litres.

19. 6 litres.

20. 20 litres.

21. 11·16 litres.

22. 128·166 grams.

23. 282·2 grams of crystallised oxalic acid, $H_2C_2O_4 + 2H_2O$, with about twice its weight of strong sulphuric acid.

$$H_2C_2O_4 \cdot 2H_2O - 3H_2O = CO + CO_2.$$

24. ·9408 gram.

25. 79·87 : 20·13 :: 1 : ·2520 (black oxide),

and 88·8 : 11·2 :: 1 : ·1261 (red oxide);

also ·2520 : ·1261 :: 2 : 1.

That is, the oxygen combined with unit weight of copper in the black oxide is twice as great as the oxygen combined with unit weight of copper in the red oxide; therefore, if the formula of the black oxide is CuO, that of the red oxide must be $CuO\frac{1}{2}$ or $Cu_2O$.

Assuming the atomic weight of copper known to be 63·5, then

$$79{\cdot}87 : 20{\cdot}13 :: 63{\cdot}5 : 16$$

and

$$88{\cdot}8 : 11{\cdot}2 :: 63{\cdot}5 : 8$$

or

$$63{\cdot}5 \times 2 : 16,$$

whence the formula is $Cu_2O$.

26. Calculated as in 25, the formula is OH or $O_2H_2$.

*27. (CH)n.*

28. The percentage composition is as follows :—

| | | |
|---|---|---|
| Nitrous oxide contains | 63·63 N | : 36·36 O. |
| Nitric oxide „ | 46·66 N | : 53·33 O. |
| Nitrous anhydride contains | 36·84 N | : 63·15 O. |
| Nitric peroxide „ | 30·43 N | : 69·56 O. |
| Nitric anhydride „ | 25·92 N | : 74·07 O. |

The ratio $\frac{O}{N}$ is represented in these several compounds by the values ·5714, 1·143, 1·7143, 2·2859, 2·8571, or ·5714 × 1, ·5714 × 2, ·5714 × 3, ·5714 × 4, and ·5715 × 5.—Q. E. D.

The percentages may be found in some of the larger text-books of chemistry, *e.g.* Miller and Fresenius. The formula must not be used, as that assumes what is to be proved.

Similarly :

| | | |
|---|---|---|
| Manganous oxide contains | Mn 77·46 | : O 22·54. |
| Red oxide „ | Mn 72·05 | : O 27·95. |
| Manganic oxide „ | Mn 69·62 | : O 30·38. |
| Black oxide „ | Mn 63·21 | : O 36·79. |

From these the weight of oxygen with unit weight of manganese in the several compounds is

·29099, ·38792, ·43637, ·58203,

which are in the ratio

1 : 1·33 : 1·5 : 2,

whence the relation is obvious.

Again :

| | | |
|---|---|---|
| Chromous oxide contains | Cr 76·47 | : O 23·53 |
| Intermediate oxide „ | Cr 70·90 | : O 29·10 |
| Green oxide „ | Cr 68·42 | : O 31·58 |
| Chromic anhydride „ | Cr 52·00 | : O 48·00 |

Hence the proportions of oxygen combined with unit weight of chromium are

·3077, ·4104, ·4616, ·9230,

which are in the ratio of

1 : 1·33 : 1·5 : 3

29. (*a*) $Na_2 + 2OH_2 = 2ONaH + H_2$ V.
Sodium. Water. Sodium hydroxide. Hydrogen.

(*b*) $Fe + H_2SO_4.H_2O = FeSO_4.H_2O + H_2$ IV.
Iron. Sulphuric acid. Ferrous sulphate. Hydrogen.

(*c*) $2HCl = H_2 + Cl_2$ , . . . . V.
Hydrochloric acid. Hydrogen. Chlorine.

(*d*) $SO_2 + H_2O_2 = H_2SO_4$ . . . . . I.
Sulphur dioxide. Hydrogen dioxide. Sulphuric acid.

(*e*) $3MnO_2 = Mn_3O_4 + O_2$
Manganese dioxide. Manganous-manganic oxide. Oxygen.

I. and V.

$$3MnO_2 = Mn_2O_4 + MnO_2$$
$$= (Mn_2O_3 + MnO) + O_2$$

(*f*) $OKH + HCl = KCl + H_2O$ . . V.
Potassium hydroxide. Hydrochloric acid. Potassium chloride. Water.

(*g*) $O_2H_2 + O_3 = OH_2 + O_2$ . . . V.
Hydrogen dioxide. Ozone. Water. Oxygen.

(*h*) $SO_3 + H_2O = H_2SO_4$ . . . . . I.
Sulphur trioxide. Water. Sulphuric acid.

(*i*) $PH_3 + HI = PH_4I$ . . . . . I.
Phosphine Hydrogen iodide. Phosphonium iodide.

(*j*) $N_2O_5 + H_2O = 2HNO_3$ . . . . . V.
Nitric anhydride Water. Nitric acid.

(*k*) $P_2O_5 + 3H_2O = 2H_3PO_4$ . . . . . V.
Phosphoric anhydride. Water. Phosphoric acid.

(*l*) $2KI + Cl_2 = 2KCl + I_2$ . . V.
Potassium iodide. Chlorine. Potassium Chloride. Iodine.

Probably in two stages, thus :—

$$KI + ClCl = KCl + ICl \text{ (iodine monochloride)}$$
$$KI + ICl = KCl + I_2.$$

(*m*) $C_2H_4$ + $Br_2$ = $C_2H_4Br_2$ . . . . I.
Ethylene. Bromine. Ethylene dibromide.

(*n*) $NaNO_3$ + $H_2SO_4$ = $HNO_3$ + $NaHSO_4$ V.
Sodium nitrate. Hydrogen sulphate. Hydrogen nitrate. Sodium-hydrogen sulphate.

(*o*) $2KClO_3$ = $KCl$ + $KClO_4$ + $O_2$
Potassium chlorate. Potassium chloride. Potassium perchlorate. Oxygen.

Probably preceded by a rearrangement :—

$$2KClO_3 = KClO_2 + KClO_4$$
$$= KCl + O_2 + KClO_4;$$

or a kind of double decomposition :—

$$2KClO_3 = 2KClO_2 + O_2$$
$$= KCl + KClO_4 + O_2.$$

(*p*) $MnO_2$ + $SO_2$ = $MnSO_4$ . . . . I.
Manganese dioxide. Sulphur dioxide. Manganese sulphate.

(*q*) $MnO_2$ + $2SO_2$ = $MnS_2O_6$ . . . . I.
Manganese dioxide. Sulphur dioxide. Manganese dithionate.

(*r*) $C_2H_4O_2$ + $3Cl_2$ = $C_2HCl_3O_2$ + $3HCl$ $V_3$.
Acetic acid. Chlorine. Trichloracetic acid. Hydrochloric acid.

(*s*) $K_2S$ + $CS_2$ = $K_2CS_3$ . . . . I.
Potassium monosulphide. Carbon bisulphide. Potassium thiocarbonate.

(*t*) $C_6H_5HO$ + $HNO_3$ = $C_6H_4NO_2HO$ + $H_2O$ $V_3$.
Phenol. Nitric acid. Nitrophenol. Water.

(*u*) $C_2H_4O_2$ + $PCl_5$ = $C_2H_3OCl$ + $POCl_3$ + $HCl$
Acetic acid. Phosphorus pentachloride. Acetyl chloride. Phosphoryl chloride. Hydrochloric acid.

Probably preceded by

$$C_2H_3OOH + PCl_5 = C_2H_3OCl + P(OH)Cl_4 \quad V.$$

and

$$P(OH)Cl_4 = POCl_3 + HCl \quad . \quad . \quad . \quad II.$$

(*v*) $\underset{\text{Terpene.}}{C_{10}H_{16}} + \underset{\text{Hydrochloric acid.}}{HCl} = \underset{\text{Camphene hydrochloride.}}{C_{10}H_{17}Cl} \quad . \quad . \quad . \quad . \quad I.$

(*w*) $\underset{\text{Hydrochloric acid.}}{3HCl} + \underset{\text{Nitric acid.}}{HNO_3} = \underset{\text{Water.}}{2H_2O} + \underset{\text{Nitrosyl chloride.}}{NOCl} + \underset{\text{Chlorine.}}{Cl_2}$

Probably preceded by

$$HCl + HNO_3 = HHO + NO_2Cl \quad . \quad . \quad . \quad V.$$

and

$$NO_2Cl + 2HCl = H_2O + NOCl + Cl_2 \quad IV.$$

(*x*) $\underset{\text{Arsenic trioxide.}}{As_2O_3} + \underset{\text{Nitric acid.}}{2HNO_3} + \underset{\text{Water.}}{2H_2O} = \underset{\text{Arsenic acid.}}{2H_3AsO_4} + \underset{\text{Nitrogen trioxide.}}{N_2O_3}$

Probably preceded by

$$As_2O_3 + 2HNO_3 = As_2O_5 + 2HNO_2 \quad . \quad IV.$$

$$As_2O_5 + 3H_2O = 2H_3AsO_4 \quad . \quad . \quad . \quad . \quad V.$$

$$2HNO_2 = H_2O + N_2O_3 \quad . \quad . \quad . \quad V.$$

(*y*) $\underset{\text{Sodium-ammonium-hydrogen phosphate.}}{NaNH_4HPO_4} = \underset{\text{Sodium metaphosphate.}}{NaPO_3} + \underset{\text{Ammonia.}}{NH_3} + \underset{\text{Water.}}{H_2O} \quad II.$

(*z*) $\underset{\text{Disodium-hydrogen phosphate.}}{2Na_2HPO_4} = \underset{\text{Sodium pyrophosphate.}}{Na_4P_2O_7} + \underset{\text{Water.}}{H_2O} \quad . \quad V.$

30. 24182·7 c.c.

31. 2510·47 c.c.

32. 8080 grams.

33. 1466·6 grams.

34. $\dfrac{5747}{2{\cdot}29\,s + 4{\cdot}32 \times {\cdot}2438}$. If s (spec. heat of phosphoric anhydride) be taken as ·2, the answer is 3803°.

35. $\dfrac{34034 - (606{\cdot}5 \times 9)}{(9 \times {\cdot}475) + (26{\cdot}7 \times {\cdot}2438)} = 2650°.$

## SECTION III.

| | Atomic weights. | Equivalents. |
|---|---|---|
| 2. Mercury . . | 200 | 100 or 200 |
| Zinc . . . | 65 | 32·5 |
| Chlorine . . | 35·5 | 35·5 |
| Iodine . . . | 127 | 127, rarely $\frac{127}{3}$? |
| Sulphur . . | 32 | $\frac{32}{2}$ or $\frac{32}{4}$ or $\frac{32}{6}$ |
| Iron . . . | 56 | 28 or $\frac{2}{3}$ of 56 |
| Copper. . . | 63·5 | 31·75 or 63·5 |

$H_2S = 34.$ $PCl_5 = 208{\cdot}5.$
$AsH_3 = 78.$ $H_2SO_4 = 98.$

3. ·4711 gram.

4. ·6220 gram. or 6·942 litres.

6. 54·4.

7. From the spec. heat 109·3. The multiple of 56 which falls nearest to this is 112.—*Ans.*

8. The atomic weight is 49·4 × 4, whence the spec. heat is ·03137.

12. Empirical formula from the percentages $CH_2O = 30$. 35·5 parts by weight of chlorine replace 1 part by weight of hydrogen, and 100 parts chloracetic acid consist of 37·5 chlorine and 62·5 of acetic acid minus the hydrogen replaced by 37·5 of chlorine. Then

37·5 : 35·5 :: 62·5 : Molecular weight − 1.

*Ans.*—59·16 + 1 = 60·16 or rather 60, and the formula is $C_2H_4O_2$.

15. $S''$, $S^{iv}$ or $S^{vi}$, $(SH_2, SO_2, SO_3)$
$O''$, $Cl'$, $(OH)'$, $(NH_4)'$, $(NH_3)''$
$(NH_2)'$, $(NH)''$, $N'''$, $(N_2)''$, $(PO)'''$, $(SO_2)''$.

16. $NaF$ . $Ag_2SO_4$ . $Hg(CN)_2$ . $(Hg_2)_3(PO_4)_2$
$Ba(ClO_3)_2$ . $BiCl_3$ . $Fe_2SiO_4$ . $Cu(C_2H_3O_2)_2$
$Fe_2(NO_3)_6$ . $Cr_2(C_2O_4)_3$ . $Sn_3(PO_4)_4$ . $Ca(ClO)_2$

19. $Cu_2 + Cl_2$ . Zn.

20. 108 × ·057 = at. wt. of M × ·0306.
Whence M = 201·17.
The nearest multiple of 70 is 210.
*Ans.* 210 . $MCl_3$.

24. $C_2H_6O$.

26. $C_2H_4O$.

27. $C_5H_8$.

28. $C_{22}H_{24}NO_7$.

29.

| | |
|---|---|
| Magnetic pyrites | $Fe_7S_8$ |
| Iron peroxide | $Fe_2O_3$ |
| Hydrogen peroxide | HO or $H_2O_2$ |
| Cryolite | $Na_3AlF_6$ |
| Mannite | $C_3H_7O_3$ or $C_6H_{14}O_6$ |
| Benzoic acid | $C_7H_6O_2$ |
| Caffeine | $C_4H_5N_2O$ or $C_8H_{10}N_4O_2$ |
| Cane sugar | $C_{12}H_{22}O_{11}$ |
| Uric acid | $C_5H_4N_4O_3$ |

30. $C_{10}H_{15}NO$ and $C_{10}H_{16}NOCl$.

33. $C_7H_4O_2$ or $C_{14}H_8O_4$.

34. $Te_2As_2S_7$.

35. $C_3H_3Cl_3N_2O_2$ or $CH_3(C_2Cl_3O)N_2O$.

36. $UCl_5$ or $U_2Cl_{10}$.

37. $C_7H_6O_2$.

38. $C_8H_{10}N_4O_2 = 194$.

39. $C_2H_7N = (C_2H_5)H_2N$ = Ethylamine.

40. $H_2C_5H_6O_4$ = Pyrotartaric acid.

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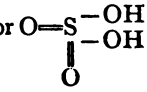
## SECTION IV.

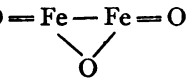
13. Common salt, NaCl, or Na − Cl
Caustic potash, KHO, or K − O − H
Sulphuric acid, $H_2SO_4$, or

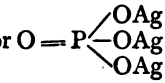


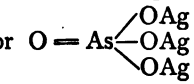
Baryta, BaO, or Ba = O

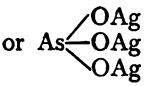
Barium peroxide, $BaO_2$, or 

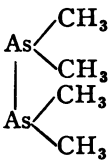
Lead peroxide, $PbO_2$, or 

Iron peroxide, $Fe_2O_3$, or 

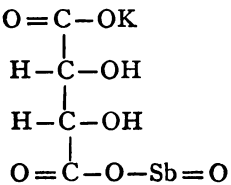
Silver phosphate, $Ag_3PO_4$, or 

Silver arsenate, $Ag_3AsO_4$, or 

Silver arsenite, $Ag_3AsO_3$, or 

Kakodyl, $As_2(CH_3)_4$, or 

Tartar emetic, $KSbOC_4H_4O_6OH_2$,

or 

23. $3H_2O.SO_3$, or $S(OH)_6$
$3HgO.SO_3$, or $S(O_6Hg''_3)$, Turpeth mineral
$3CuO.SO_3$, or $S(O_6Cu_3)$
$Al_2O_3.SO_3.3H_2O$, or $S(O_6Al_2).3H_2O$, Aluminite

25. 21·24 pounds.

26. 11·55 grams.
27. 14·59 grams.
29. Sodium 32·79 ; aluminum 13·02 ; fluorine 54·19.
30. 43·63 kilos of litharge ; 2327·8 litres of oxygen.

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## SECTION V.

1. $AgClO_3$, $AgClO_4$, $AgHSO_4$, $Ag_2SO_4$, $AgH_2PO_4$, $Ag_2HPO_4$, $Ag_3PO_4$, $AgH_3SiO_4$, $Ag_2H_2SiO_4$, $Ag_3HSiO_4$, $Ag_4SiO_4$, $AgHSO_3$, $Ag_2SO_3$, $AgH_2PO_3$, $Ag_2HPO_3$.

2.

| | | | |
|---|---|---|---|
| $NO_2Cl$ | $SO_2.OH.Cl$ | $P_2O_3(OH)_3Cl$ | $C_7H_5OCl$ |
| $NO_2NH_2$ | $SO_2Cl_2$ | $P_2O_3(OH)_2Cl_2$ | $C_7H_5ONH_2$ |
| | $SO_2.OH.NH_2$ | $P_2O_3(OH)Cl_3$ | |
| | $SO_2(NH_2)_2$ | $P_2O_3Cl_4$ | |
| | | $P_2O_3(OH)_3NH_2$ | |
| | | $P_2O_3(OH)_2(NH_2)_2$ | |
| | | $P_2O_3(OH)(NH_2)_3$ | |
| | | $P_2O_3(NH_2)_4$ | |

Benzoic acid and carbon acids generally yield also sub stitution compounds, *e.g.*—

$HOC_7H_4ClO$ Chlorobenzoic acid,
$HOC_7H_3Cl_2O$ Dichlorobenzoic acid,
&c. &c.
$HOC_7H_4(NH_2)O$ Amidobenzoic acid.

4. $S(OH)_4O = 2H_2O.SO_3$ (glacial sulphuric acid).
$S(OH)_2O_2 = H_2O.SO_3$ (oil of vitriol).
$SO_3 = SO_3$ (sulphur trioxide).
Also $S_2(OH)_2O_5$ (derived from $2S(HO)_6$) $= H_2O.2SO_3$ (Nordhausen acid).

5.

| | | | |
|---|---|---|---|
| | Sulphuric anhydride | $SO_3$ | Known |
| | Phosphoric ,, | $P_2O_5$ | ,, |
| or | Pyrophosphoric ,, | | |
| | Nitric ,, | $N_2O_5$ | ,, |
| | Nitrous ,, | $N_2O_3$ | ,, |

| | | |
|---|---|---|
| Hyponitrous anhydride | $N_2O$ | Known |
| Theiosulphuric „ | $S_2O_2$ | Unknown |
| Chloric „ | $Cl_2O_5$ | „ |
| Perchloric „ | $Cl_2O_7$ | „ |
| Acetic „ | $(C_2H_3O)_2O$ | Known |

8. Hyposulphites $O = S\begin{matrix}OM'\\H\end{matrix}$ analogous to hypophosphites and phosphites, &c. More recent experiments have, however, cast serious doubt upon this formula.

9. $2HNO_3 + PbO = Pb(NO_3)_2 + H_2O$
Nitric acid. Litharge. Lead nitrate. Water.

$HNO_3 + NH_3 = NH_4NO_3$
Nitric acid. Ammonia. Ammonium nitrate.

$H_2SO_4 + KHO = KHSO_4 + H_2O$
Sulphuric acid. Caustic potash. Potassium hydrogen sulphate.

or

$H_2SO_4 + 2KHO = K_2SO_4 + 2H_2O$
Potassium sulphate.

$H_2SO_4 + PCl_5 = SO_2.OH.Cl + HCl + POCl_3$
Sulphuric acid. Phosphorus pentachloride. Sulphuryl hydroxy-chloride. Hydrochloric acid. Phosphoryl trichloride.

or

$H_2SO_4 + 2PCl_5 = SO_2Cl_2 + 2HCl + 2POCl_3$
Sulphuryl chloride.

$(NH_4)_2SO_4 - 2H_2O = (NH_2)_2SO_2$
Ammonium sulphate. Sulphamide.

$NH_4HSO_4 - H_2O = NH_2.OH.SO_2$
Ammonium hydrogen sulphate. Water. Sulphamic acid.

$(NH_4)_2CO_3 - H_2O = NH_4O.CO.NH_2$
Ammonium carbonate. Ammonium carbamate.

$$(NH_4)_2CO_3 - 2H_2O = \underset{\text{Carbamide.}}{NH_2 . CO . NH_2}$$

$$\underset{\text{Acetyl chloride.}}{C_2H_3OCl} + \underset{\text{Water.}}{OH_2} = \underset{\text{Acetic acid.}}{C_2H_3O . OH} + \underset{\text{Hydrochloric acid.}}{HCl}$$

$$\underset{\text{Calcium hydroxide.}}{Ca(HO)_2} - \underset{\text{Water.}}{H_2O} = \underset{\text{Calcium oxide.}}{CaO}$$

$$\underset{\text{Calcium chloride.}}{CaCl_2} + \underset{\text{Sodium carbonate.}}{Na_2CO_3} = \underset{\text{Calcium carbonate.}}{CaCO_3} + \underset{\text{Sodium chloride.}}{2NaCl}$$

$$\underset{\text{Calcium carbonate.}}{CaCO_3} + \underset{\text{Ammonium chloride.}}{2NH_4Cl} = \underset{\text{Calcium chloride.}}{CaCl_2} + \underset{\text{Ammonium carbonate.}}{(NH_4)_2CO_3}$$

$$\underset{\text{Ammonia.}}{NH_3} + \underset{\text{Ethyl iodide or iodoethane.}}{C_2H_5I} = \underset{\text{Ethylammonium iodide or ethylamine hydriodide.}}{NH_3C_2H_5I}$$

$$\underset{\text{Ethylamine.}}{NH_2C_2H_5} + C_2H_5I = \underset{\text{Diethylammonium iodide or Diethylamine hydriodide.}}{NH_2(C_2H_5)_2I}$$

$$\underset{\text{Diethylamine.}}{NH(C_2H_5)_2} + C_2H_5I = \underset{\text{Triethylammonium iodide or triethylamine hydriodide.}}{NH(C_2H_5)_3I}$$

$$\underset{\text{Triethylamine.}}{N(C_2H_5)_3} + C_2H_5I = \underset{\text{Tetrethylammonium iodide.}}{N(C_2H_5)_4I}$$

$$\underset{\text{Tetrethylammonium iodide.}}{N(C_2H_5)_4I} + \underset{\text{Silver hydroxide (hypothetical).}}{AgHO} = \underset{\text{Silver iodide.}}{AgI} + \underset{\text{Tetrethylammonium hydroxide.}}{N(C_2H_5)_4HO}$$

16. 43·75 litres.

17. C 36·6, H 2·1, Ag 47·1, O 13·9.

·2705 gram. of silver.

20. $C_2H_2O_4$.

24. $C_5H_{12}O$, if an alcohol, is $C_5H_{11}OH$.

$$C_5H_{11}OH + HOC_2H_3O = \underset{\text{Acetate.}}{C_5H_{11}OC_2H_3O} + \underset{\text{Water.}}{H_2O}$$

$$C_5H_{11}OH + (HO)_2C_2O_2 = \underset{\text{Acid oxalate.}}{C_5H_{11}O \,.\, OH \,.\, C_2O_2} + H_2O$$

or

$$2C_5H_{11}OH + (HO)_2C_2O_2 = \underset{\text{Neutral oxalate.}}{(C_5H_{11}O)_2C_2O_2} + 2H_2O$$

If a primary alcohol:—

$$C_5H_{12}O + O = \underset{\text{Aldehyd.}}{C_5H_{10}O} + H_2O$$

and $C_5H_{12}O + O_2 = \underset{\text{Acid.}}{C_5H_{10}O_2} + H_2O.$

If a secondary alcohol :—

$$C_5H_{12}O + O = \underset{\text{Ketone.}}{C_5H_{10}O} + H_2O.$$

If a tertiary alcohol, oxidation yields a mixture of acids or of ketone and acid.

25. Aldehyds.

(*a*) $COH - CH_2 - CH_2 - CH_3.$

(*b*) $COH - CH = (CH_3)_2.$

Ketone $CH_3 - CO - C_2H_5.$

26. Dihydric alcohol, $C_7H_{12}(OH)_2$
Monobasic acid, $C_6H_{13}(COOH)$
Compound ether, $CH_3C_6H_{11}O_2$
or $C_2H_5C_5H_9O_2$
&c. &c.
or $C_6H_{13}CHO_2.$

28. Alcohol, $C_nH_{2n} + 1OH$
Acetate, $C_nH_{2n} + 1\,O.C_2H_3O$
Aldehyd, $C_n - 1\,H_{2n} - 1\,.CO.H$
Acid, $C_n - 1\,H_{2n} - 1\,.CO.OH$

29. $\left\{\begin{matrix}CH_2.OH\\CO.OH\end{matrix}\right.$ Monobasic glycolic acid. $\left\{\begin{matrix}CO.OH\\CO.OH\end{matrix}\right.$ Dibasic oxalic acid. also $\left\{\begin{matrix}CO.H\\CO.OH\end{matrix}\right.$ Monobasic glyoxylic acid?

31. $CH_3.COOH + PCl_5 = CH_3.COCl + HCl + POCl_3$
Acetic acid. Phosphoric chloride. Acetyl chloride.

$CH_3OH + HCl = CH_3Cl + H_2O$
Methylic alcohol. Methyl chloride, or chloromethane.

$\left.\begin{matrix}CH_3\\CH_3\end{matrix}\right\}O + 2HCl = 2CH_3Cl + H_2O$
Dimethyl oxide or ether.

$2CH_3.COOH + Ag_2O = 2CH_3.COOAg + H_2O$
Acetic acid. Silver acetate.

$CH_3OH + C_2H_5O.HO.SO_2 =$
Methyl alcohol. Ethylhydrogen sulphate, or sulphovinic acid.

$\left.\begin{matrix}CH_3\\C_2H_5\end{matrix}\right\}O + (HO)_2SO_2$
Methyl, ethyl, oxide or ether. Sulphuric acid.

$CH_3.CO(OCH_3) + NaHO = CH_3.COONa + CH_3HO$
Methyl acetate. Caustic soda. Sodium acetate. Methyl alcohol.

$(CH_3.CO)_2O + H_2O = 2CH_3.COOH$
Acetic anhydride. Acetic acid.

33. $C_{10}H_{18}O_3$.

34. $C_5H_{10}O$.

35. Percentage composition, Ba 36·93, C 25·85, H 2·18, O 35·04. Formula $BaC_8H_8O_8$ and $H_2C_8H_8O_8$.

36. $HC_9H_{10}O_2$.

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